Experimental Verification of Range-Dependent Inversion: Shallow Water Experiment 2006

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LONG-TERM GOALS

Develop methods for rapid assessment of sediment properties relevant for acoustic propagation in a range-dependent shallow water environment.

OBJECTIVES

Modal dispersion data are input to inversion schemes that estimate sediment properties in a range-independent environment. This approach has now been extended to include range-dependent environment. Simulation studies show that range-dependent sediment properties can be extracted if modal dispersion data are obtained for multiple source/receiver locations. It is proposed to collect suitable data during the Shallow Water 2006 experiment to verify the feasibility of estimating the range dependent sediment properties from modal dispersion information.

APPROACH

In shallow water, the acoustic field can be represented as a sum of contributions from a set of propagating modes. It is well known that modal dispersion data contain information about the characteristics of the shallow water wave guide including the acoustic characteristics of the sediment. Inversion scheme that use the modal dispersion data for estimating sediment acoustic properties in a range independent environment has been described in the literature [1]. This approach has been modified to determine the sediment properties in a range-dependent environment as outlined below.

Using perturbation analysis, the perturbation dt_n in the arrival time of mode n at the receiver due to perturbation in the compressional wave speed is given by

$$dt_n = \frac{\partial}{\partial \omega} \int_0^r \int_0^\infty \frac{1}{k_n(s,\omega)} \frac{\omega^2 \Delta c(s,z)}{c_b^3(s,z)\rho_b(s,z)} \left|\phi_n(s,z,\omega)\right|^2 ds dz \tag{1}$$

where ω is the frequency of the acoustic source, $k_n(s,\omega)$ is the eigenvalue of the nth mode, $c_b(s,z)$ is the unperturbed compressional wave speed of the sediment , $\rho_b(s,z)$ is the density of the sediment, $\phi_n(s,z,\omega)$ is the mode function of the nth mode, r is the range to the receiver, $\Delta c(s,z)$ is the perturbation to the compressional wave speed and s and z represent the range and depth locations. The double integral can be changed into a double sum given below.

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$$dt_n = \sum_{p=1}^{P}\sum_{q=1}^{Q} A(s_p, z_q)\Delta c(s_p, z_q) \tag{2}$$

This double sum can be reduced to a matrix equation and the equation solved to determine the quantity $\Delta c(s_p, z_q), p = 1,\cdots,P, q = 1,\cdots,Q.$ In converting to the integral to a matrix equation we assumed the region is discretized in both range and depth. The argument s_p refers to the pth step in range and z_q refers to the qth step in depth.

WORK COMPLETED

The inversion method proposed above is one of the approaches that can be used to estimate the sediment characteristics from modal data. The other method employs the modal eigenvalues as data. The Shallow Water 2006 experiment will be designed so as to collect co-located data sets so as to perform inversions using both these techniques. The overlapping data sets will provide a direct means of comparison and validation of the two inversion approaches. Measurements will be made on a common moored receive system for a towed cw point source (J15-3)/towed air gun source. In addition to the acoustic measurements, supporting environmental data will be collected using the CTD chain. The CTD chain will provide a detailed picture of the spatial sound speed structure in the water column during the acoustic transmissions.

In order to design the Shallow Water 2006 experiment, the following modeling effort was undertaken.

1. Determine the source parameters for the experiment
2. Determine the experimental configuration
3. Develop experimental plan

During August 2006, data suitable for evaluating the proposed inversion schemes were collected as part of the Shallow Water Experiment 2006.

RESULTS

A. Source parameters

The modal dispersion data provides the group velocities of the modes as a function of frequency. In order to be able to estimate the sediment characteristics over a large depth the modal dispersion data is required over a wide frequency band i.e. from frequencies on the order of tens of Hertz to hundreds of Hertz. The general approach is, therefore, to use a broad band source such as an explosive or an air gun source which have a fairly wide spectrum. However, since there was some doubt about getting clearance for use of explosive/air gun source due to their impact on the environment, the use of linear frequency modulated (LFM) signal was considered. These signals will be generated using J15 source. Unlike explosive or air gun sources, the LFM signal the instantaneous frequency varies linearly with time. The modal dispersion data is obtained by performing time-frequency of the received signal. The left panel of Figure 1 shows the modal dispersion data obtained for an LFM signal propagating in an environment similar to that of the SW06 experiment. The environment for this simulation study was obtained from an experiment conducted in the Hudson Canyon area in September 1988. The time-

frequency data were adjusted for the variation of the source signal frequency with time. It is seen from this plot that an LFM signal can be used as the source signal for the experiment. Based on these simulations a source signal whose frequency varies linearly from 40 Hz to 290 Hz over a period of 0.5 sec is recommended as the source signal. Multiple pings will be transmitted from a single source location and averaged to improve the signal to noise ratio. The ping to ping interval will be about 3 sec to allow for multi-path spread.

In earlier experiments the source depth was at about 35 m i.e. approximately half the water depth. In order to investigate whether this source depth is optimal, simulations were done to determine the wavenumber spectrum with the source at different depths. The right panel of Figure 1 shows the wavenumber spectrum for three source locations at three frequencies. It is seen that a source depth of 25 m is more suitable because the response is best at this source depth.

B. Experimental configuration

The left panel of Figure 2 shows four radial tracks in the area of the experiment. The figure also shows the modal dispersion curves for the environment along the four radial tracks. The sediment model used for this study was obtained from data collected during earlier experiments conducted in the region. The modal dispersion curves show that there is considerable variability in the dispersion data for the four tracks. The data acquired during the proposed experiment will have adequate resolution, in terms of modal dispersion, to enable estimation of the range-dependent properties of the sediment.

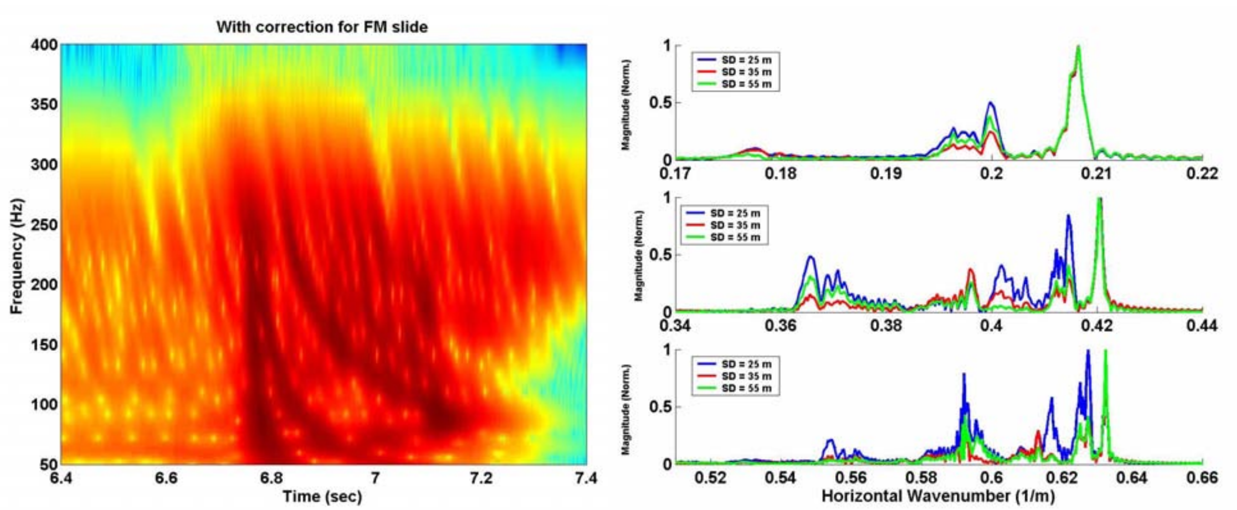

Figure 1. Left panel shows the modal dispersion curves for LFM signal. The right panel shows the wavenumber spectrum for three source depths at three source frequency.

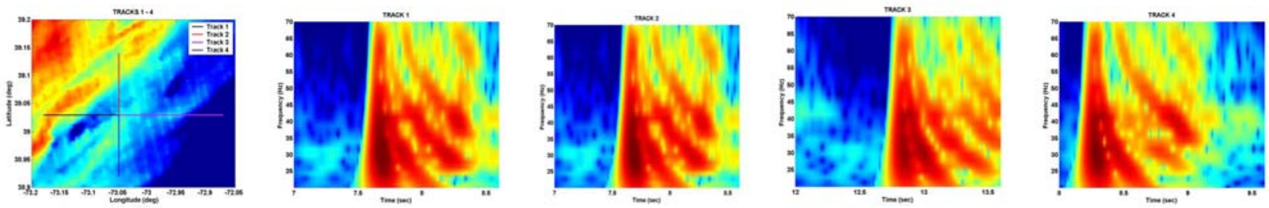

Figure 2. The plots show the four tracks (left panel) and the modal dispersion curves for propagation along the four tracks.

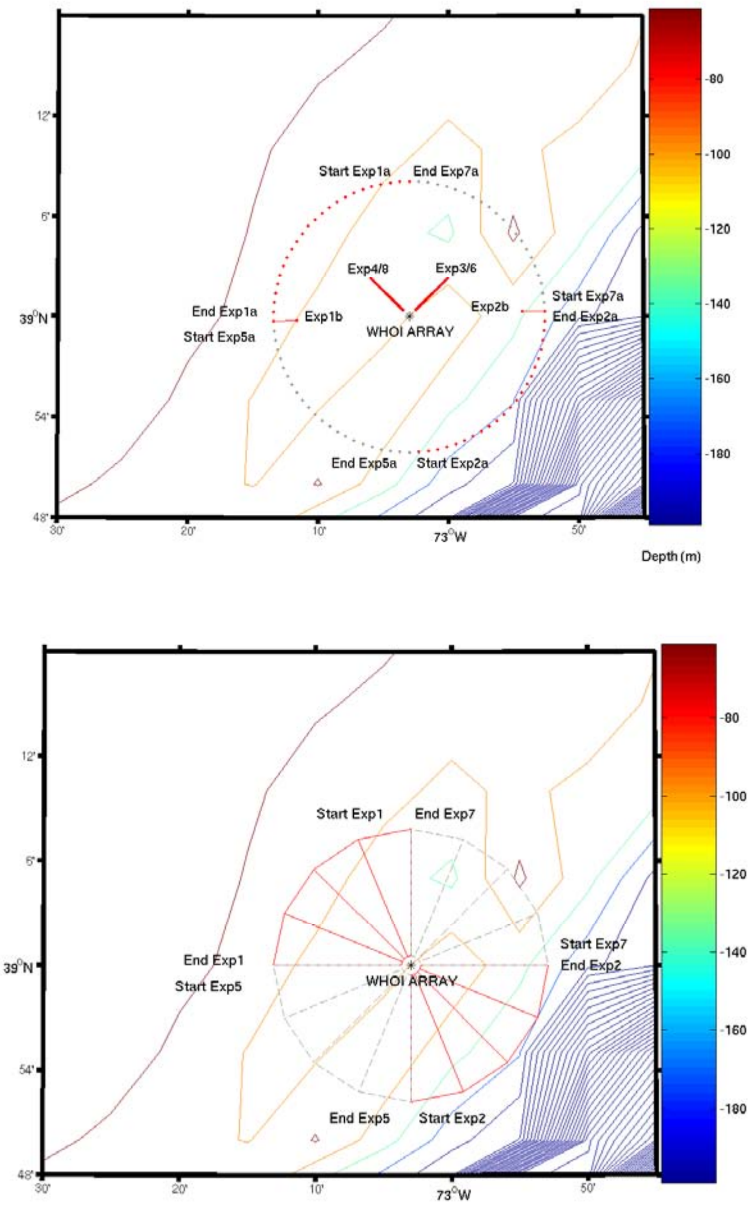

Figure 3. Top panel shows the way points for transmit signals. The bottom panel shows the tracks for CTD survey to be done during the experiment.

C. Experimental plan

In Figure 3 the plan for collecting broad band data is indicated. The way points for the transmission of the broad band signal are along the perimeter of a circle with a radius of about 15 km are indicated in the left panel. The right panel shows the tracks for the CTD survey.

D. Field Experiment

During August 2006, data to be used for this project was collected. The locations of LFM transmissions are shown in Figure 4. Each transmission consisted of an LFM with frequency varying from 40 Hz to 290 Hz over 0.5 sec. Multiple pings were transmitted at each location with a repetition interval of 2.5 sec. This separation was based on the expected multi-path spread.

IMPACT/APPLICATIONS

The data collected during this experiment will enable to validate the proposed method for estimating range-dependent sediment compressional wave speed from modal dispersion data. Data collected using a narrow band source will be used to estimate the sediment compressional wave speed from modal eigenvalues. This will enable comparison between the two methods as the data will be collected at the same time. Extensive environmental measurements taken during the experiment will help in assessing the impact variability in water column characteristics. The approach provides a means of determining the range-dependent sediment characteristcs and has the following advantages.

1. No sub-aperture processing is needed as in the case of narrowband data.
2. Use of a broadband source with adequate bandwidth will ensure good resolution of the estimates.
3. Can be used to extract the range-dependent properties of the water column as well.

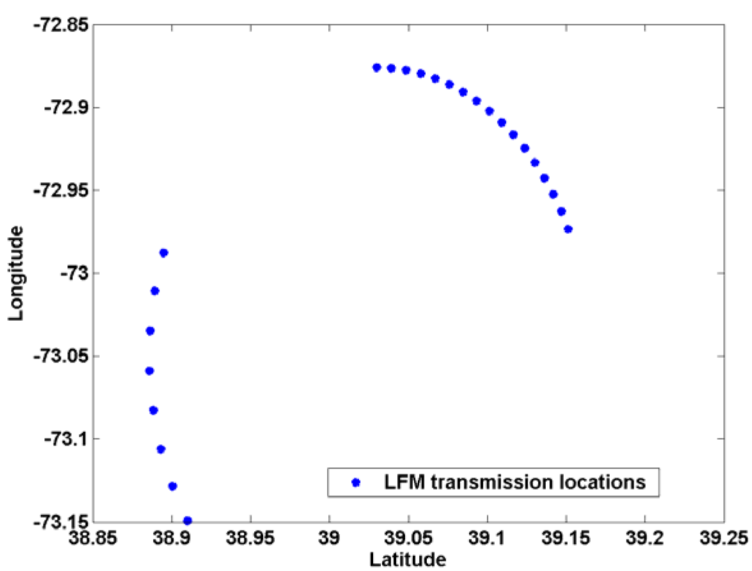

Figure 4. Locations of LFM transmissions during the field experiment conducted on August 5-6, 2006.

RELATED PROJECTS

As part of Shallow Water 2006 experiment a modal mapping experiment will also be conducted. This experiment also envisages estimation of sediment characteristics from modal eigenvalues. Results from this experiment will help in validating the results of broad band experiment outlined in earlier sections.

REFERENCES

1. J. F. Lynch, S. D. Rajan, and G. V. Frisk,"A Comparison of Broadband and Narrowband Inversions for Bottom Geoacoustic Properties at a Site Near Corpus Christi, Texas", *Journal of the Acoustical Society of America*, 89(2), 648-655, 1991.